ONERA
THE FRENCH AEROSPACE LAB

ISAE Institut Supérieur de l'Aéronautique et de l'Espace SUPAERO

PhD Proposal in AI and Computer Vision

Learning methods for vision-based autonomous landing of civil aircraft

Mario CASSARO – ONERA
Nicolas DROUGARD – ISAE-SUPAERO

- Start date of the thesis: October 2023 – Duration: 36 months.
- Key words: *aircraft autonomy, autonomous landing, runway detection/tracking, computer vision, deep learning, reinforcement learning.*

1 Introduction

In accordance with ONERA [1] and EASA [21] roadmaps, the implementation of machine learning (ML) techniques to increase the level of autonomy and reliability of aerial vehicles is a very active research area. Recent advances in vision sensors and computational performance, as well as improvements in ML techniques and algorithms, make the use of computer vision based solutions a real asset for improving guidance, navigation and control architectures, for example by enriching data fusion algorithms, resulting in better navigation performance for UAVs [24]. Moreover, these solutions are passive, inexpensive, and do not require any special equipment other than a camera and a vision processing unit on board.

ONERA and ISAE-SUPAERO have made a major contribution in recent years to the development of the most recent advances in autonomy and safety of civil aircraft based on computer vision. Despite the valuable results obtained and the numerous successful flight demonstrations, most of the developed methods were based on classical techniques, the use of data-driven algorithms was very limited, and the considered scenarios were restricted to nominal visibility conditions. Therefore, there is still a lot of room for improvement and exploration of other machine learning methods and architectures, especially regarding the landing phase of civil aircraft, in nominal and degraded visibility conditions. Indeed, the landing phase, considered by far the most critical phase, can benefit from computer vision tools that provide information to the pilot, and can even partially or completely control the aircraft. Vision-based landing is the first specific example detailed in the EASA CoDANN (Concepts of Design Assurance for Neural Networks) report [6], and requires the identification of the landing runway on the images produced by the sensors.

2 Project

The proposed PhD thesis aims at developing, implementing and analyzing different machine learning solutions to robustly detect landing sites (runways), and safely guide a civil aircraft (simulation model), during the entire approach and landing phase, based on visual sensors (cameras). The three main objectives of the thesis are:

– Runway detection: the image processing techniques used so far for runway detection are mainly based on low-level feature extraction and/or prior knowledge of the geographical data of the landing site [23, 19]. This thesis therefore first proposes to use the latest machine learning methods, and suitable neural network structures [4], for airport runway detection, using labeled datasets from an image generator.

– Tracking: the thesis will then naturally progress towards runway detection from video streams. Indeed, the performance of runway detection can be improved, and in particular be robust to occlusion, sensor failures, or weather conditions, thanks to the implementation of tracking methods [25], which can be based on recurrent neural networks [15].

– Aircraft control: until now, the vision-based control architectures proposed for autonomous landing consist in inferring additional information of the aircraft deviation from the runway axis through visual sensors, in order to be able to use the classical guidance and piloting laws, as in [17] or for the ATTOL (Autonomous Taxi Take-Off and Landing) project [3, 2]. However, state of the art reinforcement learning (RL) algorithms allow to compute a control strategy for visual environments, from numerous simulations [16]. The last phase of this thesis will therefore consist in setting up such a simulator in order to be able to evaluate the performance of vision-based RL algorithms to compute camera-based autopilots for landing.

A recently developed toolbox for labeled runway dataset generation, available at ISAE-SUPAERO, and a new flight simulation platform equipped for vision processing, available at ONERA, will be used by the candidate for development and validation purposes.

3 Methods and Challenges

Computer vision algorithms have been improving very fast since the rise of deep learning, whether they concern classification [9], localization, detection [7], segmentation [5] or tracking [25]. In addition, a common technique consisting in using pre-trained networks on particular datasets, accelerates learning and improves the performance and the robustness of the obtained solutions (transfer learning, [22]). However, runway detection in aerial imagery is a challenging task due to the wide variety of contextual information and imaging conditions such as camera exposure, weather conditions, and viewing angles. In addition, the topological similarity with other existing contexts (e.g., highways, rivers, and coastlines) makes the feature identification process remarkably complex. Different methods have been studied to solve the runway detection problem and are described in [4].

Regarding pixel-based RL [16], it gained a lot of interest as early as 2015, and many advances have been made since then [12, 11, 13]. Originally developed for discrete action systems, the algorithms that will be developed in this thesis for aircraft landing, will take advantage of recent advances allowing to produce continuous commands [14] and be compared to state of the art methods, such as [17] or the ATTOL project [3]. Particular attention will be paid on the one hand to promote models with good generalization properties, for example with the help of real data [10], and on the other hand to methods ensuring a certain explicability level, such as model-based RL, or possibly explainable RL [8], in accordance with the EASA CoDANN report [6]. Finally, the reward function, that defines the optimization criterion of the associated RL problem, is naturally sparse in the landing context, which must be taken into account for effective learning of control strategies [20].

4 Guidelines

For the three main phases of this thesis, *i.e.* runway detection, runway tracking, and guidance/control for landing, the study will proceed according to the following steps:

- a literature review of the domain, in order to identify the different classes of methods and state of the art algorithms to implement;
- the implementation, adaptation, training and evaluation of the selected algorithms and methods;
- the definition and the implementation of a benchmark, *i.e.* an evaluation of the algorithms trained in various learning contexts, using relevant performance metrics, in order to analyze the pro and cons of the different approaches;
- the proposal and evaluation of a new algorithm, or a new method, inspired for instance by the analysis of the benchmark results, the review of the literature, or the visual landing context.

This work will be performed with the help of classical deep learning libraries such as Pytorch [18]. Although the algorithms will be prototyped on personal computers, training sessions that last for a long time and especially the benchmark execution, will run on the ISAE-SUPAERO supercomputer, in order to benefit from parallel and GPU computing.

5 PhD candidate profile

The candidate must have a Master's degree in Artificial Intelligence, Computer Vision, Computer Science or Mathematics. Specifically, she/he must have:

- Advanced knowledge in Machine Learning/Deep learning for Vision;
- Advanced programming experience with Python and Machine Learning libraries;
- Good communication and writing skills in English; Ability to work independently.

Knowledge on Flight Dynamics would be appreciated but is not mandatory.

6 Application procedure

Formal applications should include a detailed resume, a motivation letter and transcripts of master's degree. Samples of published research by the candidate and reference letters are appreciated but not necessary. Applications should be sent by email to:

- Mario CASSARO (`firstname.lastname@onera.fr`);
- and Nicolas DROUGARD (`firstname.lastname@isae-supaero.fr`).

References

[1] Onera roadmap. https://www.onera.fr/fr/feuille-de-route. Accessed: 2022-10.

[2] Acubed. Wayfinder project. https://acubed.airbus.com/blog/wayfinder/how-wayfinder-is-using-neural-networks-for-vision-based-autonomous-landing/.

[3] ONERA Airbus. Attol project. https://www.airbus.com/en/newsroom/press-releases/2020-06-airbus-concludes-attol-with-fully-autonomous-flight-tests. 2020.

[4] Rasna A Amit and C Krishna Mohan. A robust airport runway detection network based on r-cnn using remote sensing images. *IEEE Aerospace and Electronic Systems Magazine*, 36(11):4–20, 2021.

[5] Vijay Badrinarayanan, Alex Kendall, and Roberto Cipolla. Segnet: A deep convolutional encoder-decoder architecture for image segmentation. *IEEE transactions on pattern analysis and machine intelligence*, 39(12):2481–2495, 2017.

[6] EASA AI Task Force and AG Daedalean. Concepts of design assurance for neural networks (codann) ii. 2021.

[7] Ross Girshick. Fast r-cnn. In *Proceedings of the IEEE international conference on computer vision*, pages 1440–1448, 2015.

[8] Alexandre Heuillet, Fabien Couthouis, and Natalia Díaz-Rodríguez. Explainability in deep reinforcement learning. *Knowledge-Based Systems*, 214:106685, 2021.

[9] Mahbub Hussain, Jordan J Bird, and Diego R Faria. A study on cnn transfer learning for image classification. In *Advances in Computational Intelligence Systems: Contributions Presented at the 18th UK Workshop on Computational Intelligence, September 5-7, 2018, Nottingham, UK*, pages 191–202. Springer, 2019.

[10] Katie Kang, Suneel Belkhale, Gregory Kahn, Pieter Abbeel, and Sergey Levine. Generalization through simulation: Integrating simulated and real data into deep reinforcement learning for vision-based autonomous flight. In *2019 international conference on robotics and automation (ICRA)*, pages 6008–6014. IEEE, 2019.

[11] Ilya Kostrikov, Denis Yarats, and Rob Fergus. Image augmentation is all you need: Regularizing deep reinforcement learning from pixels. *arXiv preprint arXiv:2004.13649*, 2020.

[12] Michael Laskin, Aravind Srinivas, and Pieter Abbeel. Curl: Contrastive unsupervised representations for reinforcement learning. In *International Conference on Machine Learning*, pages 5639–5650. PMLR, 2020.

[13] Misha Laskin, Kimin Lee, Adam Stooke, Lerrel Pinto, Pieter Abbeel, and Aravind Srinivas. Reinforcement learning with augmented data. *Advances in neural information processing systems*, 33:19884–19895, 2020.

[14] Timothy P Lillicrap, Jonathan J Hunt, Alexander Pritzel, Nicolas Heess, Tom Erez, Yuval Tassa, David Silver, and Daan Wierstra. Continuous control with deep reinforcement learning. *arXiv preprint arXiv:1509.02971*, 2015.

[15] Anton Milan, S Hamid Rezatofighi, Anthony Dick, Ian Reid, and Konrad Schindler. Online multi-target tracking using recurrent neural networks. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 31, 2017.

[16] Volodymyr Mnih, Koray Kavukcuoglu, David Silver, Andrei A Rusu, Joel Veness, Marc G Bellemare, Alex Graves, Martin Riedmiller, Andreas K Fidjeland, Georg Ostrovski, et al. Human-level control through deep reinforcement learning. *nature*, 518(7540):529–533, 2015.

[17] Mariusz Oszust, Tomasz Kapuscinski, Dawid Warchol, Marian Wysocki, Tomasz Rogalski, Jacek Pieniazek, Grzegorz Henryk Kopecki, Piotr Ciecinski, and Pawel Rzucidlo. A vision-based method for supporting autonomous aircraft landing. *Aircraft Engineering and Aerospace Technology*, 90(6):973–982, 2018.

[18] Adam Paszke, Sam Gross, Francisco Massa, Adam Lerer, James Bradbury, Gregory Chanan, Trevor Killeen, Zeming Lin, Natalia Gimelshein, Luca Antiga, et al. Pytorch: An imperative style, high-performance deep learning library. *Advances in neural information processing systems*, 32, 2019.

[19] Yiming Pi, Luhong Fan, and Xiaobo Yang. Airport detection and runway recognition in sar images. In *IGARSS 2003. 2003 IEEE International Geoscience and Remote Sensing Symposium. Proceedings (IEEE Cat. No. 03CH37477)*, volume 6, pages 4007–4009. IEEE, 2003.

[20] Martin Riedmiller, Roland Hafner, Thomas Lampe, Michael Neunert, Jonas Degrave, Tom Wiele, Vlad Mnih, Nicolas Heess, and Jost Tobias Springenberg. Learning by playing solving sparse reward tasks from scratch. In *International conference on machine learning*, pages 4344–4353. PMLR, 2018.

[21] Artificial Intelligence Roadmap. A human-centric approach to ai in aviation. *European Aviation Safety Agency*, 1, 2020.

[22] Chuanqi Tan, Fuchun Sun, Tao Kong, Wenchang Zhang, Chao Yang, and Chunfang Liu. A survey on deep transfer learning. In *Artificial Neural Networks and Machine Learning–ICANN 2018: 27th International Conference on Artificial Neural Networks, Rhodes, Greece, October 4-7, 2018, Proceedings, Part III 27*, pages 270–279. Springer, 2018.

[23] Jingzhe Wang, Yue Cheng, Jianchun Xie, and Wensheng Niu. A real-time sensor guided runway detection method for forward-looking aerial images. In *2015 11th International Conference on Computational Intelligence and Security (CIS)*, pages 150–153. IEEE, 2015.

[24] Yoko Watanabe, Augustin Manecy, Alexandre Amiez, Shin Aoki, and Sho Nagai. Fault-tolerant final approach navigation for a fixed-wing uav by using long-range stereo camera system. In *2020 International Conference on Unmanned Aircraft Systems (ICUAS)*, pages 1065–1074. IEEE, 2020.

[25] Rui Yao, Guosheng Lin, Shixiong Xia, Jiaqi Zhao, and Yong Zhou. Video object segmentation and tracking: A survey. *ACM Transactions on Intelligent Systems and Technology (TIST)*, 11(4):1–47, 2020.